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The Peloponnese continental margin from Zakynthos Island to Pylos: morphology and recent sedimentary processes

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ABSTRACT Funded by the EEC Sixth Framework Program, the SEAHELLARC project was aimed to evaluate, and better understand the causes, of the various natural geohazards (chiefly earthquakes and tsunamis), which frequently affect the western Peloponnese area and particularly its coastal domain; this region is one of the most seismically active of Greece and therefore of the Mediterranean Sea. Based on a set of new geophysical data, such as detailed swath bathymetry and high-resolution sub-bottom Chirp, we have distinguished and studied four contrasted domains along this area of the Peloponnese active continental margin underlined by intense crustal seismicity and marked by very contrasted and often sharp continental slopes; from east to west these are: (1) an area including the continental shelf and the upper slope; there sedimentary overload and destabilizations, syn-sedimentary faults, mass transport deposits and active sedimentary by-pass mechanisms are the main risk factors. (2) The middle to lower continental slopes, is mainly expressed by two, N-S trending, fault-related, depressions, where active deformations, well recorded by actual tilting of the sedimentary blanket, occur. (3) West of this deep structural depressions exists a poorly sedimented ridge area (from which merges the small Strophades Islands) also showing N-S and E-W trending lineaments resulting in a dense network of fractures and scarps and leading too a particularly complex sub-marine morphology; this area, together with the westernmost deep domain (4), which bounds the continental margin, clearly records the effects of significant active tectonic. Our studies of the shallow and recent sedimentary cover of the continental margin off western Peloponnese, confirm that this active margin segment is an area where geohazards can be expected. In addition to fault ruptures, generated at depth by the specific tectonic framework, sedimentary collapses, particularly along the shelf break nearby Cape Katakolo, may trigger significant local tsunamis, which may in turn induce strong damages all along the nearby coasts up to the town of Pylos.

Key words: Peloponnese continental margin, natural geohazards, morphology, tectonic, sedimentary destabilization, mass transport deposit, swath bathymetry, Chirp data, SEAHELLARC.

1. Introduction

Western Peloponnese (Fig. 1) is an area repeatedly affected by large magnitude earthquakes occurring offshore and onshore mainly as consequences of the convergence and ongoing collision between the western, previously strongly deformed, continental border of the Aegean sub-plate and the deep Ionian Sea and Apulia domains; the last significant event (magnitude 6.4) occurred near Patras in June 2008. Despite progress in house construction and earthquake monitoring systems, this seismic activity has episodically caused destruction and human loss; the recent population growth and extensive urbanization along the coasts, particularly in the vicinity of the towns of Pirgos and Pylos, have increased, during the last decades, the risks from earthquakes and tsunamis. These were the reasons for the Sixth Framework Program of EEC to support a dedicated project, the SEAHELLARC project [SEismic and tsunami risk Assessment and mitigation scenarios in the western HELLenic ARC: see Papoulia *et al*. (2014a)]. Among the objectives of this project, one was to provide a detailed submarine morphological-geological background of this area of the western Peloponnese continental margin knowing that: 1) the majority of earthquakes proceeds from ruptures occurring beneath the continental slope; 2) their cumulated effects have generated, through geological times, specific tectonic features which affect the basement and its sedimentary cover and can be identified, mapped and tentatively dated; and **3)** by shaking the most recent and unconsolidated sedimentary blanket, earthquakes may generate large scale submarine failures along the continental slope that are able to trigger tsunamis.

To better define and evaluate the seabed morphology a detailed mapping of the bathymetric characteristics of an area of approximately 12,000 km^2 (200 km by 60 km) has been performed in spring 2007 onboard the OGS R/V ”Explora” using multibeam sonar swath mapping techniques (Figs. 1 and 2). In addition to swath bathymetry the shallow structure (up to 100 m penetration depending of the area) of the recent sedimentary cover was imaged using a high-resolution sub-bottom Chirp system. These data have been used, concurrently with the detailed morphological maps, to better asses the various active geological processes, particularly slope by-passing and failures, debris flows, and faulting likely driven by the significant earthquake/tectonic activities which characterise the area and are imprinted on the sea floor.

2. General geological background and setting

The survey area is located along the western Peloponnese continental margin, between the Island of Zakynthos to the north and the coast of Messinia Peninsula (Fig. 1). This margin segment, facing the deep Ionian basin, represents a domain of the western border of the active Hellenic subduction (McKenzie, 1972; Le Pichon and Angelier, 1979). Onshore the area includes the outcrops of the Gavrovo, Ionian, and pre-Apulian, Alpine units, which were emplaced as thrust sheets during several episodes of the Alpine/Hellenides tectonic evolution between Upper Oligocene and Lower/Middle Pliocene. These units show a general NNW - SSE tectonic trend (Aubouin, 1977). Along the coast of Kyparissiakos Gulf these rocks are locally covered by continental, lacustrine and marine, Pleistocene to Holocene, deposits cut by E-W extensional active faults (Papanikolaou *et al*., 2007). Offshore only little information is available; Lyberis and Bizon

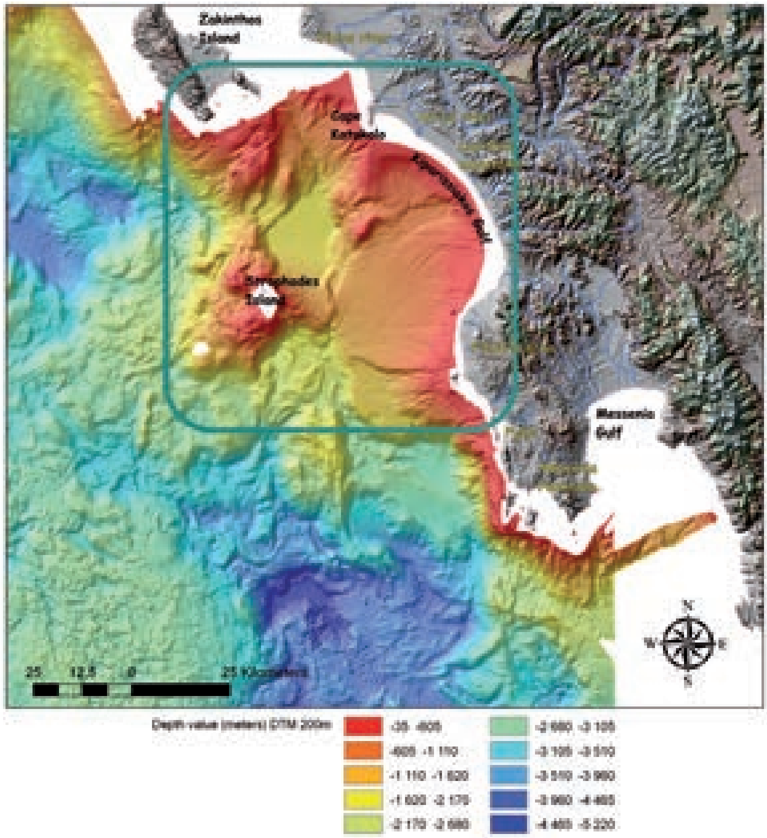


Fig. 1 - General morphology of the Peloponnese continental margin between the Island of Zakynthos and the Gulf of Messinia. Shaded DTM at 200 m, based on (a) swath data, (within the green frame) recorded during the R/V Explora Survey (SEAHELLARC project in 2007), completed by (b) data from the Medee Survey acquired in 1995 (Chamot-Rooke *et al.*, 2005) and (c) data collected in 2006 by the R/V Aegaeo from the Hellenic centre for Marine Research.

(1981) have stressed the probable play of a significant Pleistocene uplift of Strophades, which they tentatively correlate to a WSW-ENE discontinuity detected within the margin sedimentary cover. Using seismic and drilling data Monopolis and Bruneton (1982) have indicated a Plio-Quaternary sedimentary blanket directly overlying the Ionian Alpine thrusted units, themselves emplaced on Neogene strata. West of Zakynthos, Brooks and Ferentinos (1984) have shown the presence of a wide syncline-type depression filled by thick Quaternary sequences mainly made of slumps and debris flow deposits. Along the Kyparissiakos continental shelf Papanikolaou *et al*. (2007) suspect, on the basis of various rates of subsidence that they tentatively relate to active coastal faults, that major physiographic changes occurred during the Pleistocene to Holocene regional evolution.

3. Bathymetry and morphology

3.1. Data acquisition and processing

Onboard the R/V "Explora" swath bathymetric data were collected using Reson Multibeam Echo-sounders Seabat 8111 and Seabat 8150; the first system operating from shallow areas (few tens of meters) down to a depth of about 400 m, the second from few hundred meters to full ocean depth. The Seabat 8111, operating at a frequency of 100 kHz, reaches the maximum swath width (about 7.5 times the water depth) when used in less than 150 m of water. The

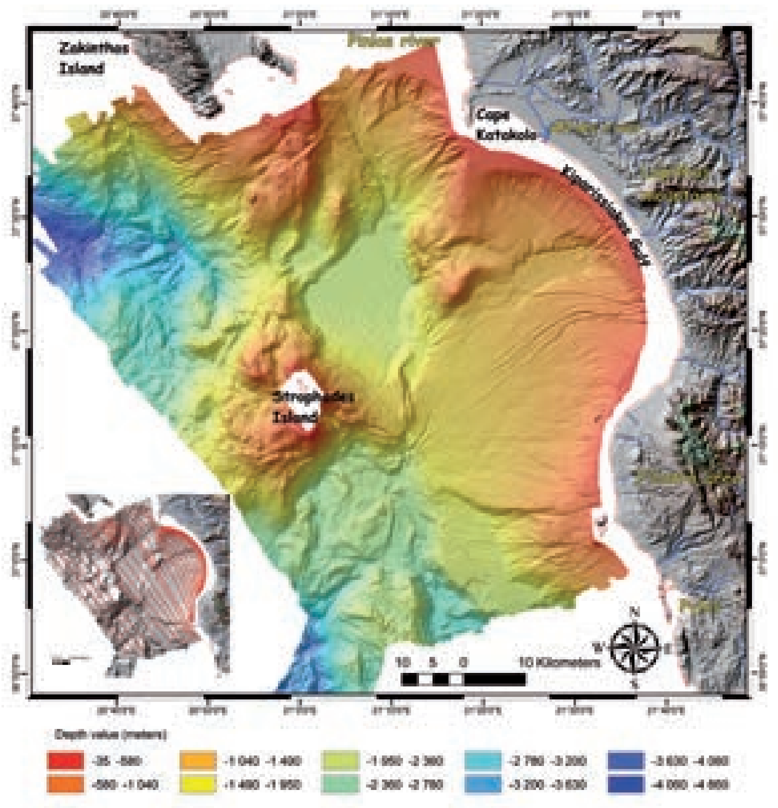


Fig. 2 - Morphology of the studied area (from the Island of Zakynthos to the area of Pylos), based on swath bathymetric data collected by the R/V Explora (DTM at 50 m). Note the very narrow continental shelf, the wide plateau-like middle slope (bypassed by several active channels related to canyons and gullies), the westward bordering Strophades deep basin, the Zakynthos - Strophades massive Ridge and the deep bordering continental slope. In insert, track lines of the R/V Explora swath survey in 2007.

system illuminates a swath on the sea floor of 150º and consists of 101 individual beams each of 1.5° across track. The Seabat 8150, operating at a frequency of 12 kHz, is a full ocean depth multibeam echo sounder system that forms 234 receiver beams to cover a total angular swath also of 150°. Sound velocity measurements were made frequently to correct the multibeam data during the processing sequence.

In the studied area, the water depth ranges from about 40 m, close to the Peloponnese shore and in the surroundings of Strophades and Zakynthos islands, to about 4700 - 4800 m in the deep basin west of Zakynthos. A total surface of about 9200 km^2 was effectively mapped during the survey, which was mainly conducted following NW-SE tracks roughly parallel to the bathymetry and shorelines. Some additional lines were recorded to guarantee good swath coverage where abrupt changes in topography and water depth caused the swaths lateral extension to significantly decrease. In some areas, such as in the surrounding of Strophades and Zakynthos, and in water depth of less then 400 m, both swath systems were used. The data quality was generally very good.

A preliminary processing was performed on board the R/V “Explora”, but the main, more accurate, processing was carried out subsequently at the OGS Data Processing Centre in Trieste. Using all available swath data a high-resolution bathymetric map [digital terrain model (DTM) at 50 m] has been produced (Fig. 2). Inspection of this map clearly indicates that the area corresponds to a morphologically complex margin segment bounded westwards by the Ionian extension of the Mediterranean Ridge (circa 3200 m water depth), and towards the south by the Matapan Trench, the deepest trough (up to 5100 m deep) known in the Mediterranean Sea. Classically, the Mediterranean Ridge is believed to represent a thick wedge of strongly deformed sediments

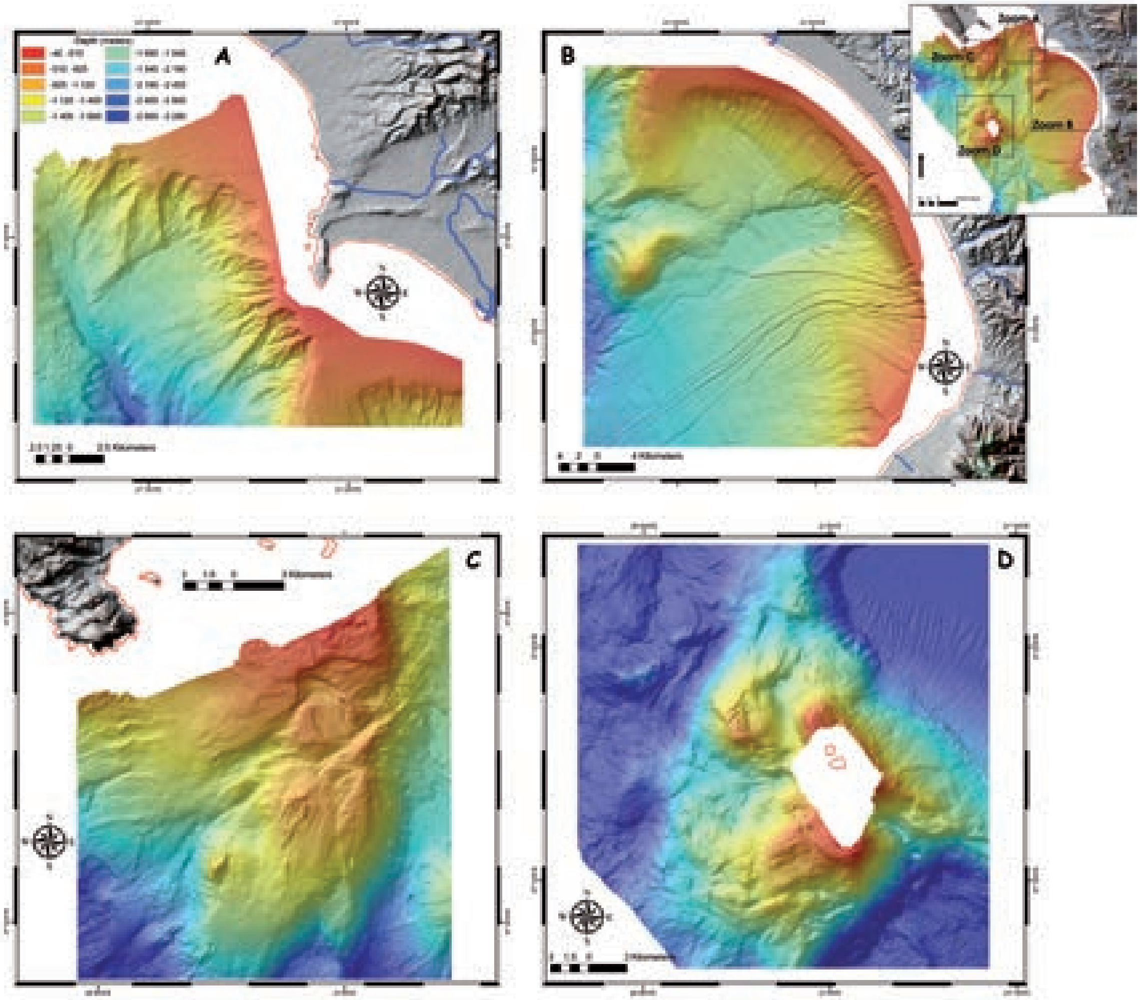


Fig. 3 - Four details (DTM at 10 m grid) of the morphology of the studied area.
A - The upper slope west of Cape Katakolo showing many small canyons, gullies and sedimentary scars.
B - The area just west of Kyparissiakos Gulf, with a very narrow shelf, many gullies and slope-bypassing channels; its northern shelf area is subjected to syn-sedimentary faulting leading to important destabilizations and submarine slides.
C - The acoustic basement ridge just south of the Zakynthos Island which appears shaped by many probable fault scarps.
D - The massive acoustic basement rise from which the small Strophades Islands are emerging.
In insert, locations of the four illustrated areas on a general morphologic map.

emplaced as a consequence of the active Hellenic subduction. During the past twenty years the Hellenic trenches have themselves often been considered as a subduction zone; there is however now a consensus to interpret these discontinuous and deep depressions as a series of fore-arc-type basins, located on the backstop of the subduction, and presently subjected to shear tectonics.

3.2. Interpretation

The 50-m DTM map (Fig. 2) shows four main morphologic provinces (Fig. 3):

- an eastern (upper slope/shelf) domain: this area includes a relatively flat, almost plateau-like, upper slope domain, bounded eastwards by a narrow continental shelf (no more than 10 km wide on average) and westwards, between 1500- and 1900/2000-m water depth, by an almost N-S trending, and very steep, middle slope. The flat upper slope can itself be subdivided into: a) a northern segment, characterized by numerous morphologic features (scarps, sedimentary scars, canyons, fault zones, etc.) showing various trends and reflecting various processes such as sedimentary collapses, erosion canyons and tectonic lineaments, and b) a southern, wider, and plateau-like sub-domain cross-cut by several channel-levee systems indicating recent sedimentary by-passing. Towards the south the slope plateau is sharply interrupted by a series of E-W-oriented lineaments which can be followed up to the continental shelf;

- a deep basins domain (water depth between 2000 and 2500 m): at the foot of the previous province this deeper area, which we refer to as the Strophades deep basins, includes two sub-basins; a northern one (2000 m water depth on average) just NE of Strophades Islands showing a very flat bottom slightly tilted towards NW; and a deeper (up to 2500 m) southern sub-basin (Figs. 1 and 2) displaying a very rough seabed progressively deepening southwards and connecting to the Matapan Trench system (Chamot-Rooke *et al*., 2005);
- westwards, the depression is bounded by a prominent and elongated ridge from where emerge the small Strophades Islands and, to the north, Zakynthos Island. This ridge can itself be divided into: a) a southern domain, the more or less patchy Strophades “swell”, bounded on its SE by very steep slopes, and b) the southern submerged extension of Zakynthos Island mainly cut by prevailing N-S and shorter E-W trending lineaments;
- to the west (i.e., toward the bordering Mediterranean Ridge) this massive ridge is bounded by a continental slope characterised by a complex morphological network where N-S and ENE-WSW trends are dominant.

The possible resolution of a multibeam survey depends on a number of factors. The major factors, however, are the water depth and the angle between the individual formed beams. Since the angles are constant on this system, it follows that the lateral distance between adjacent beams increases with water depth. In this area, where water depths vary from 20 to over 3000 m there is a considerable difference in the possible resolution between these two extremes and hence the grid sizes that can be used in processing. The original DTM with a grid size of 50 m was a compromise to cover the whole area in a single grid. To better detail the various morphological characteristics in the shallower water however, smaller portions of the bathymetric data set were reprocessed to produce DTM using a grid size of 10 m, (see Fig. 3).

Fig. 3A shows an enlargement of the NE domain and particularly the southern lobe of the Alphea River submarine delta; the upper most continental slope (between 200 and 300 m) appears affected by numerous slide scars indicating recent sedimentary instabilities (northern sector) and cut by small canyons/gullies some of which may be located on fault zones (southern sector); the deepest area correlates with a wide (2 to 5 km) channel through which sediments are likely transported from the Pinios River system to the northern Strophades deep basin; small spoon-shaped scarps seen on the western side of this channel also indicate occurrences of sedimentary instabilities at this depth (around 1300 / 1400 m).

Fig. 3B illustrates the detail of the sea floor offshore the northern Kyparissiakos Gulf. In the area the upper continental slope shows three main features: a) in the northern sector numerous slide scars, indicating frequent sedimentary instabilities, are seen in close connection with small linear scarps (faults?) and gullies; b) in a central domain numerous gullies and canyons are converging around 1000 m of water depth to create a wide (5 - 7 km) flat-bottomed depression; c) the southern sector is cut by a series of more or less linear channels; three of them appear to be directly connected to canyons originating from the shelf; sediments from nearby coastal rivers are likely caught by these canyons and by-passing through the middle slope to be finally trapped in the deep southern Strophades basin.

Figs. 3C and 3D show details of the seabed respectively south of Zakynthos and around the Strophades Islands. South of Zakynthos we note a dense network of NE-SW trending lineaments bounding alternatively foundered and uplifted blocks probably corresponding to a series of horsts and grabens; around the Strophades Islands the seafloor is particularly rough and no specific trend can be detected with the possible exception of a ENE-WSW one, which seems to cut the ridge into two pieces; its linear steep south-eastern slope directly faces the southern Strophades deep basin.

4. Chirp data

4.1. Acquisition and processing

Sub-bottom profiling acquisition was performed throughout the cruise, both during the bathymetric survey and the ocean bottom seismometers (OBSs) seismic acquisition (see Papoulia *et al.*, 2014b). The R/V "Explora" was equipped with a Chirp sub-bottom profiler Benthos CAP-6600 made of 16 keel mounted AT 471 transducers and a top side unit including an analogue amplifier and a data logger. The system digitally synthesizes and transmits a linearly swept, frequency-modulated Chirp pulse with resolution inversely proportional to the transmitted bandwidth. This process ensures high-resolution images of the seafloor and sub-bottom layers. The Chirp output is a long FM pulse that provides a high signal to noise ratio, which, combined with the matched filter correlation, results in significant resolution and penetration. The signal processing substantially reduces transducer ringing and side lobes, which is imperative for shallow water operation. About 2850 km of profiles were acquired during the survey (see Fig. 2, insert). Normally, the system is operated in multi-ping mode during which the system transmits a ping at constant time intervals, listens, and records, during those same intervals. The operator modifies these intervals (or recording window) to maintain the water-bottom and the sub-bottom sedimentary sequence in the centre of the window. A drawback of this system is that, after the matched filter and Hilbert transform to a set number of samples (8192), different length windows have the same number of samples but different sample intervals. These differences have usually to be resolved in subsequent processing. However, due to limitations of personnel during the cruise the sub-bottom profiler was run only in automatic mode using a constant ping interval, and hence recording window length, of 540 ms. Subsequently, all the data were converted into SEGY format both at 1 ms sample rate for a general visualisation, and at 0.2 ms sample rate for more detailed studies at higher resolution. However, only graphic displays have been used for this study. Two types of Chirp information have been selected: a) characteristic echo-facies, which can be interpreted as representative of the various processes operating on this margin segment (see Table 1), even if no sedimentological calibration from core samples was available; and b) Chirp sections showing typical records of sedimentary processes, or tectonic features (Figs. 4 to 8).

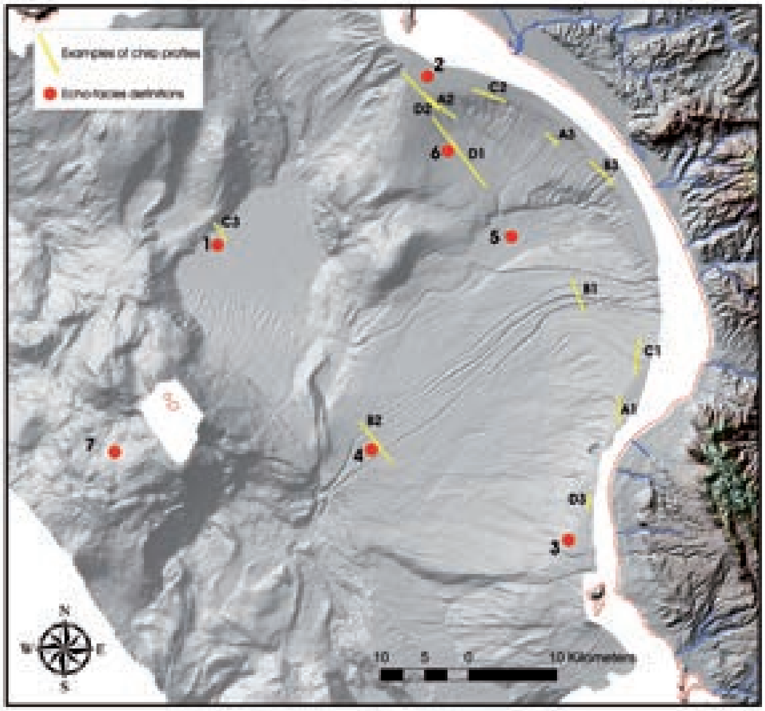


Fig. 4 - Locations (in yellow) of the several Chirp examples discussed in text and shown on Figs. 5 to 8; in red dots, locations of the different selected echo-facies discussed in text and shown on Table 1.

4.2. Interpretation

Our interpretation is based on echo-character analysis carried out in various sedimentary settings (see for example Damuth and Hayes, 1977; Damuth, 1980, 1994; Damuth and Flood, 1983; Pratson and Laine, 1989; Loncke *et al.,* 2002), which have shown that high-frequency echograms (3.5 - 12.0 kHz) provide a useful tool to evaluate near-bottom sediment morphology, or acoustic characteristics, and to infer the various sedimentary types and related sedimentary processes that shape the sea floor.

4.2.1. Main observed echo facies

On the basis of acoustic clarity and continuity of bottom and sub-bottom reflectors and micro-topography of the sea floor, we may have identified 12 different echo types that have been grouped for simplification into 7 main echo characters (see Table 1 and Fig. 4 for location):

1) bedded characters made of distinct bottom echo types with parallel and continuous sub-bottom reflectors, with penetration > than 50 ms (about 40 - 45 m);
2) bedded characters, similar to 1 but with penetration between 30 and 50 ms (25 - 40 m);
3) bedded characters but with restricted penetration between 20 and 30 ms (20 - 25 m);
4) bedded characters with very little but detectable penetration less than 10 ms (a few m);
5) transparent echo facies, including transparent echo-types showing reflective bottom echoes with transparent sub-bottom;
6) rough, discontinuous and chaotic echo characters; this echo facies corresponds to weak bottom echo types without obvious sub-bottom reflectors; occasionally it contains wavy but sharp bottom echo types with chaotic, intermittent, sub-bottom reflectors and discontinuous weak bottom reflectors, partly chaotic;

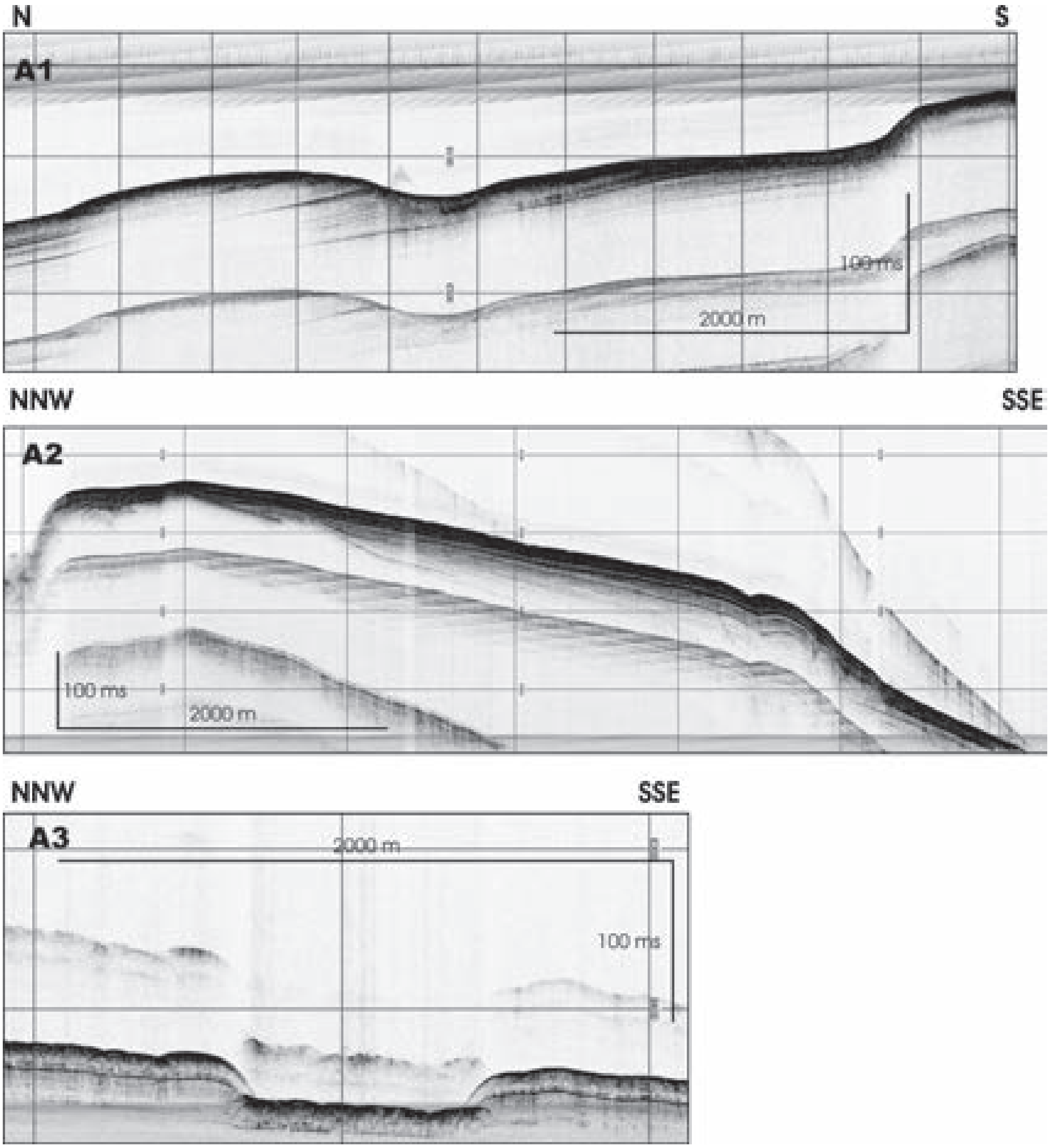
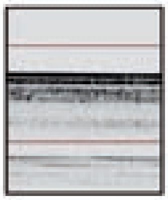
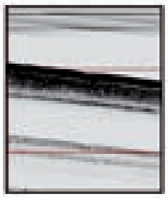
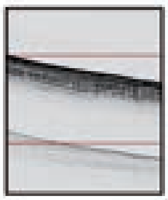
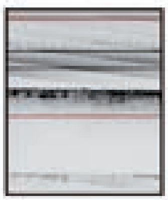
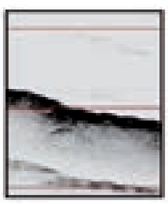


Fig. 5 - Examples of Chirp sections illustrating various configurations of erosional surfaces (see locations on Fig. 4):
A1 - active erosion on the border of the continental shelf;
A2 - erosion surface covered by a recent sedimentary blanket;
A3 - erosion, or non deposition, within one of the gully/channel cutting across the upper continental slope.

7) no penetration; regular or irregular reflection-free bottom; small, regular hyperbolic bottom echoes without sub-bottom reflectors, or hyperbolic echo characters expressed by large, irregular hyperbolic bottom echoes.

Each echo type displays variations in reflectivity and in penetration that are unique to each domain. Moreover, although transitions from one to another echo type could be sharp, they appear often to be gradual.

Table 1 - Each Chirp seismic signature is classified into seven main echo facies; each echo facies has particular meanings and is generally associated with specific sediment types generated by specific sedimentary processes.

Chirp seismic signature	Echo-facies	Geological/morphological interpretation
	Bedded thickness > 50 ms	Layered sedimentary infilling of lower slope basin
	Bedded thickness 50 - 30 ms	Layered sedimentary cover of uppermost slope/platform
	Bedded between 30 - 20 ms	Layered sedimentary cover of continental slope and platform
	Bedded less than 10 ms	Thinly layered sedimentary cover on middle slope
	Reflection-free (transparent)	Coarse deposits
	Irregular, rough	Sedimentary slide, reworked sediments
	No penetration, hyperbolae	Irregular acoustic basement along slope

4.2.2. Relationships between echo characters, sedimentary types, and depositional processes

According to correlation with sea floor sampling (see Loncke *et al.*, 2002; Domzig *et al.*, 2009), which have provided a basis for identifying specific sedimentary types and, finally, depositional processes for most of the echo types, we propose the following relationship:

- continuous bedded echo characters (1, 2, 3, 4) may be either attributed to detrital sediments deposited by turbidity currents (1) or to upper slope/shelf prograding accumulations (2) and (3); these echo types may locally also include hemi-pelagic or pelagic thin cover (4);
- transparent echo characters (5) are interpreted to indicate deposits due to stacked coarse debris flows at the foot of coalescing canyons;
- rough, discontinuous and chaotic echo characters (6): rough, chaotic, sometimes wavy echo characters are usually interpreted to indicate highly disorganized sediments induced by mass-wasting processes such as slumping;
- no penetration, hyperbolic echo characters (7): this echo facies corresponds to probable lithified sediments or basement (hard rocks); hyperbolic echo have different meanings depending on the size, shape, and spacing of the hyperbolae. The occurrence of hyperbolae is mainly related to the degree of roughness of the sea floor topography. Large, irregular hyperbolae are associated with rough topographies such as basement highs, fault scarps, and rugged slopes, which mask the real underlying echo facies. Small, regular hyperbolae are commonly associated with deposits generated by mass-wasting processes and appear in this area chiefly associated with irregular slopes, almost void of soft sediment.

It should be noted that, although some echo characters can be directly attributed to specific sedimentary deposits and associated processes (e.g., transparent echo types generally correspond to gravity driven mass-flow deposits) but the same sedimentary process can be expressed by different types of echo characters; transparent echo characters and small hyperbolic echo characters may both represent mass flow deposits. In turn, some echo types may also indicate different types of sediments generated by different kinds of sedimentary processes; the bedded echo characters, which generally indicate turbidites, may also correspond to mixed hemi-pelagites or pelagites.

Before attempting any correlation to a given depositional process echo types should be placed in their physiographic and geological context. This is what we have attempted on Fig. 4, which shows, on a shaded morphological background, the locations of 7 short typical Chirp sections.

- Erosion processes (Fig. 5): sections A1, A2 and A3 illustrate erosion surfaces at different depths; A1 shows a surface void of recent sedimentation extending at the foot of the present continental shelf (between 100- and 150-m water depth) due either to non deposition or to active erosion during a former Quaternary low stand; A2, offshore Cape Katakolo, indicates a truncated surface around -180 m, but covered by about 50 m of recent sediments; A3 illustrates a corridor (at 390- m water depth) void of soft sediment and probably subjected to active erosion leading to an indurate surface.
- By-passing features (Fig. 6): sections B1 and B2 illustrate three active channels respectively on the upper and middle slope through which sediments derived from the onshore relief, and transported by coastal rivers, are directly driven into the deep bordering Strophades basins; these channels, well displayed on the morphological map, are quite linear and bounded by small levees, particularly in their distal parts. Section B3 shows a

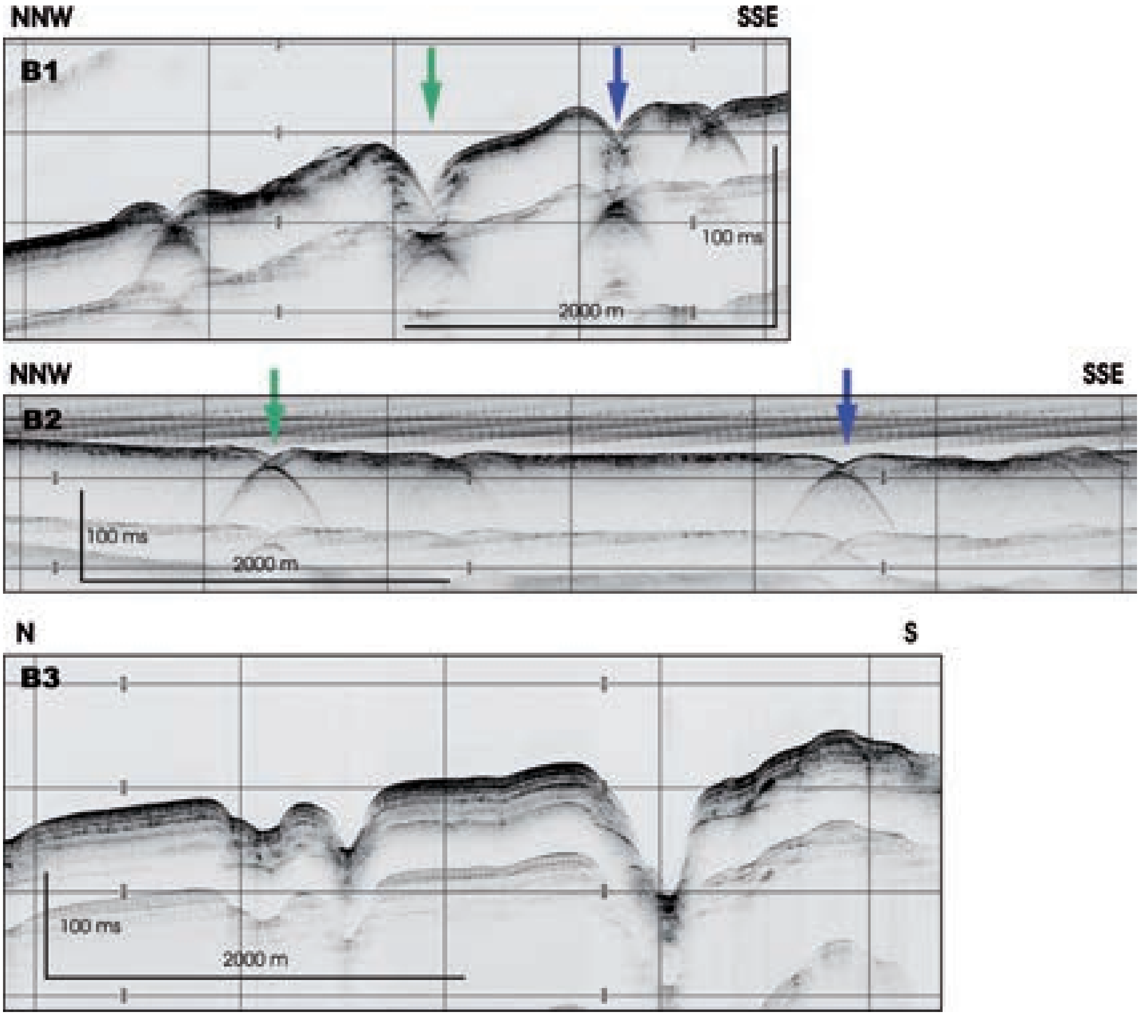


Fig. 6 - Examples of Chirp sections illustrating various active channels and canyons across the upper to middle continental slope (see locations on Fig. 4):
B1 - two channels and levees across the upper slope;
B2 - the same at the base of the middle slope; small levees can still be identified;
B3 - one canyon and two gullies cutting across a relatively sedimented upper slope section.

canyon and several gullies near the continental shelf and cutting across relatively thick recent sedimentary cover; this supports the theory that these features are probably due to erosion processes related to river floods.

- Sedimentary blanketing (Fig. 7): several areas of the margins are loci of relatively thick recent sedimentation; C1 and C2 are typical sections across the continental shelf; thick recent sediments (C3) are also infilling the northern deep Strophades basin (circa -1900 m). In the first case the thickening is likely due to the presence of local depocentres (prograding wedges related to coastal rivers); in the second case turbidites, delivered by channel-levee systems, are trapped into a tectonically active basin.
- Sedimentary destabilisation and tectonics (Fig. 8): in several areas, and chiefly in the shallow NE corner, sub-bottom data show evidence of several sedimentary

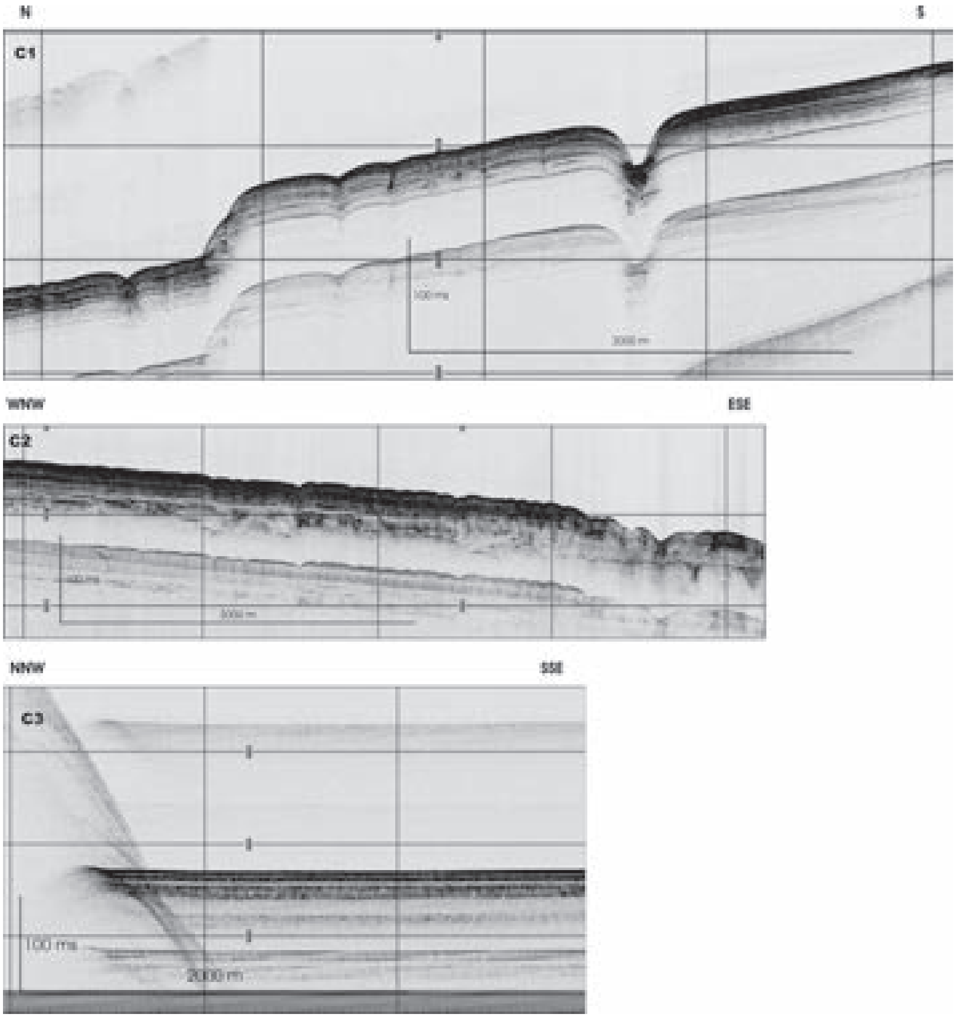


Fig. 7 - Examples of Chirp sections illustrating various settings of recent sedimentary cover (see locations on Fig. 4):
C1 - the upper most continental slope showing a constant thickness of probably Holocene sediments;
C2 - along the shelf edge off Cape Katakolo the recent sedimentary blanket cut by numerous syn-sedimentary faults;
C3 - east of the Strophades Islands the recent turbiditic infill of a deep basin.

destabilizations at various scales; on one of the most spectacular example (D1) we observe a recent slide scar and, along the slope, a mass transport deposit characterized by its irregular and chaotic acoustic facies. Good examples of syn-sedimentary tectonics are seen across areas of the uppermost slope, and particularly south of Cape Katakolo; section D2 illustrates several syn-sedimentary faults (at 200- to 250-m water depth), which will likely be the origin of future sedimentary destabilisation. Finally several lines, across, or near the continental shelf, have recorded sharp sub-vertical offsets which we interpret as evidence of active, or recently active, faults cutting across lithified sediments, or even Alpine basement rocks (D3); these structural trends are chiefly seen nearby onshore areas where active tectonics have been reported Papanikolaou *et al.* (2007).

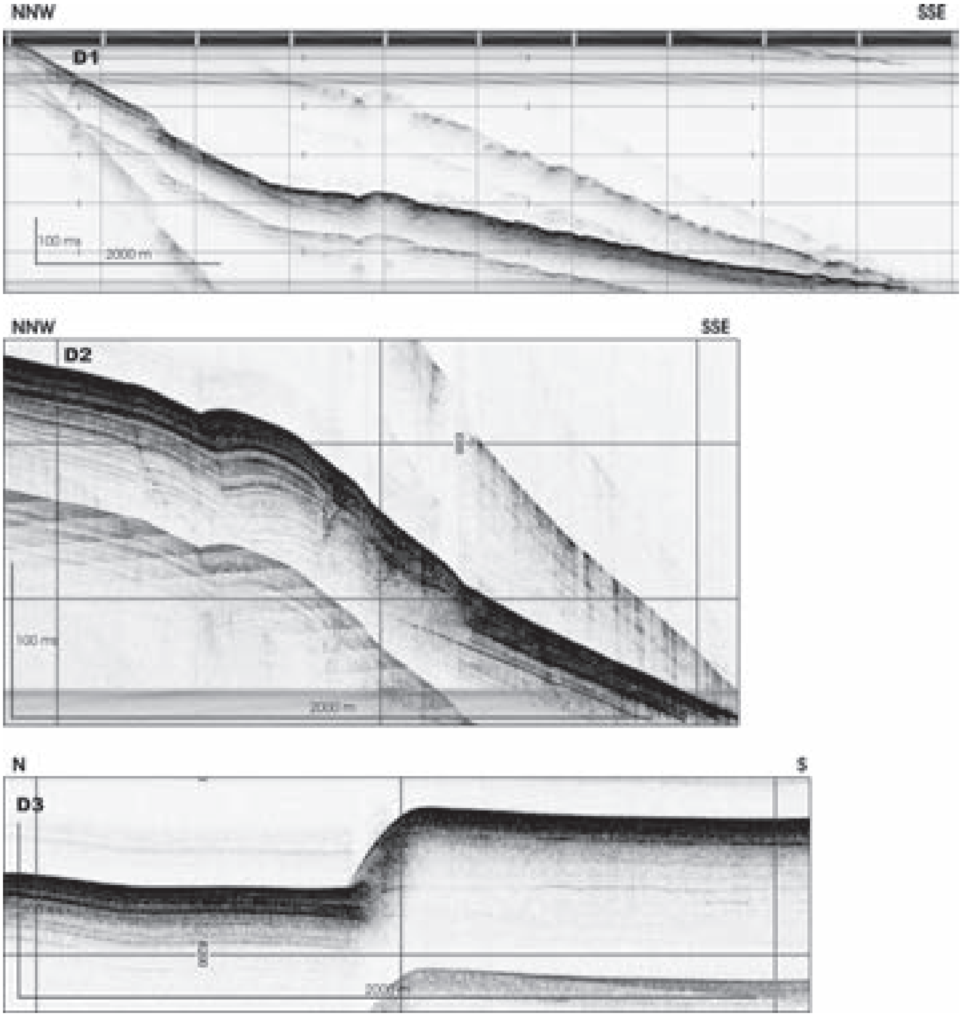


Fig. 8 - Examples of Chirp sections illustrating various processes affecting the recent sedimentary cover (see locations on Fig. 4):
D1 - on the upper slope south of Cape Katakolo sedimentary scars and the resulting debris flow;
D2 - along the shelf edge south of Cape Katakolo ongoing sedimentary destabilisation; note the syn-sedimentary faults progressively cutting the unstable sedimentary blanket;
D3 - on the shelf north of Pylos a probable recent extensional fault offsetting the seafloor.

A repartition of the different echo facies is shown, superposed on the morphology of the margin (Fig. 9). From this map we may stress the following characteristics:

- Along the coasts of Kyparissiakos Gulf, roughly between Cape Katakolo and the area of Pylos, four recent depocentres (thickness in excess of 50 m) are detected along the shelf edge and uppermost slope area; following Papanikolaou *et al*. (2007) we correlate these sediments, clearly linked to coastal rivers, to Holocene deposits uncomformably covering late Pleistocene prograding wedges. We are however unable to detect, from our data set, any coast-parallel offshore fault network as identified by Papanikolaou *et al*. (2007). The only evidence of detected faults are: a) north of Kyparissiakos Gulf, an E-W trending fault system which corresponds to recent syn-sedimentary structures, b) a NNE-SSW

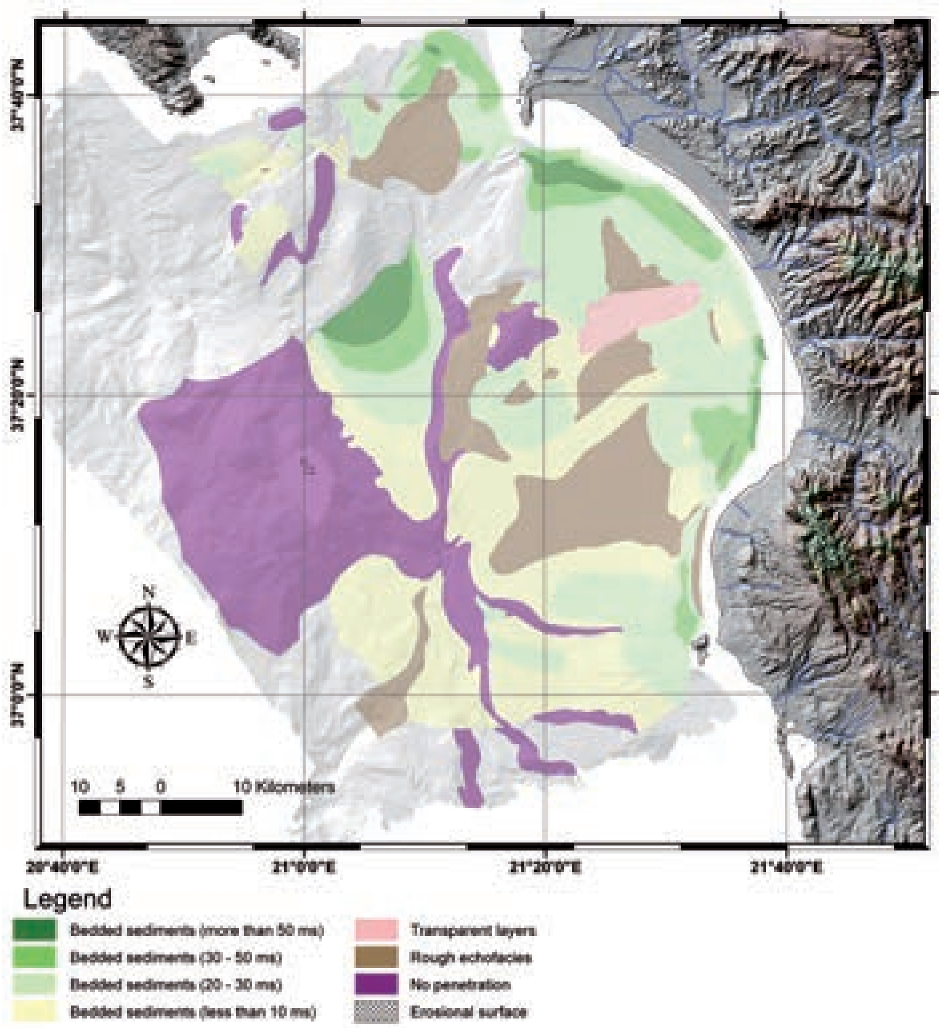


Fig. 9 - Echo-facies map as deduced from the interpretation of Chirp data along most of the track lines shown on the insert of Fig. 2. The map illustrates the occurrence of recent depocentres along the continental shelf; these thickenings are presumed to relate to nearby coastal rivers; a dissymmetric depocentre also characterises the northern sector of the deep basin just north of the Strophades Islands; this is due to the trapping of clastics transiting across the upper slope; most of the upper to middle slope corresponds to an area of destabilized or reworked sediments; the ridge south of Zakynthos and around the Strophades Islands consists of an acoustic basement almost devoid of any significant sedimentary cover.

fault zone following the same trend as the Cape Katakolo offshore tectonic lineaments, c) offshore the town of Filiatra, a series of recent E-W trending fault scarps. The network of syn-sedimentary faults, seen north of Kyparissiakos Gulf, is likely to trigger in a near future significant sedimentary destabilisation in an area already suspected to be unstable by Papanikolaou *et al*. (2007).

- Northern Strophades deep basin: within the deep elongated basin (1900- to 2000-m water depth), located between Strophades Ridge and the foot of the middle slope, the penetration of the recent (Holocene?) cover as indicated by our acoustic data reaches up to 100 ms (circa 80 m); this basin is presently trapping hemi-pelagites and turbidites chiefly transiting from the shallower domain east and north of Zakynthos through a N-S channel (2 - 3 km wide) running between the southern submerged extension of Zakynthos and the Pinios River sedimentary fan; a progressive tilting of this basin towards N-NW is attested by its dissymmetric sedimentary infill.

- Most of the upper to middle slope seabed off the Kyparissiakos Gulf coast consists either of wide areas of recent, coarse (or reworked) sediments building cone-like features in relation to the various shelf depocentres, or of narrow areas through which sediments are directly by-passing to be trapped at the foot of the slope. In the northern corner of this region clear evidence exists of sedimentary destabilisation, including relatively thick mass transport deposits (D1 on Fig. 8). We believe that these instabilities are triggered by syn-sedimentary faulting, that may be related to overloading along the shelf edge, but we cannot exclude seismicity as a triggering mechanism; in this case the sub-surface syn-sedimentary fault network will be reflecting deeper tectonic features. Offshore the Lapithas region an intriguing, (6 - 8 km wide) and almost flat depression, characterized by a transparent echo-type extends at the foot of a series of a canyon/gully systems running across the upper slope; we infer that this feature is an area where coarse eroded sediments, transiting directly through canyons and gullies, were spread in late Pleistocene times and may are still spreading today.
- Only little information may be extracted from the Chirp data concerning the Strophades/ Zakynthos Ridge and the bordering western continental slope. In the whole area, as well as all along the eastern slope of the ridge, the acoustic signal is almost reflection-free (no penetration) or is characterized by slope hyperbolae. In this region the rough seafloor is cut by many scarps of various directions and inferred to result from intense fracturing. From place to place a few graben-like depressions have however trapped thin pockets of sediments (only a few meters thick).

5. Conclusions

Combining the detailed bathymetric and Chirp data allows four contrasted domains to be distinguished on this segment of the Peloponnese active continental margin; these are, from east to west:

- west of a quite narrow continental shelf, itself characterized by a few unstable depocenters and syn-sedimentary faulting, extends an upper, locally thickly sedimented continental slope, where two main sedimentary processes are operating: a) quite active sedimentary by-pass mechanisms, well attested by numerous gullies, canyons and channel-levee systems through which the products of intense erosion operating onshore are transiting to be trapped at the foot of the continental slope in deep bordering tectonic basins, and b) large-scale sediment failures, destabilizations and mass transport deposits particularly detected in the vicinity of Cape Katakolo. These features are likely triggered by an arc-shaped fault system developing offshore Alfios River mouth. We suspect that these faults are generated by recent sedimentary overload but we cannot exclude seismic shaking as a consequence of nearby active tectonics;
- at the foot of this upper slope runs a deep, N-S trending, tectonic depression divided into two deforming sub-basins; the northern one is slightly tilted towards NW;

- these two deeps are bounded to the west by a massive and highly fractured acoustic basement ridge from which merge the islands of Strophades and Zakynthos;
- the western border of this ridge correlates with a steep and morphologically complex slope where approximately N-S and E-W trending lineaments concur to create a dense network of fracture scarps; this slope segment constitutes a progressive transition towards the nearby, deep and folded western Mediterranean Ridge, which represents itself a tectono-sedimentary prism emplaced as a consequence of the Hellenic subduction.

Concerning more specifically the risk assessments, the morpho-bathymetric and Chirp data collected during the SEAHELLARC cruise of the RV "Explora" clearly illustrate that this segment of the Peloponnese margin results from, and has recorded, the effects of recent and significant tectonic activity; this is well attested by its intense overall fracturing, the presence of deep, elongated, tilted and deformed bordering slope basins. An unexpected result has been to recognise the importance of large-scale marine failures and sedimentary destabilisation. Our observations demonstrate there is a real potentiality of sedimentary collapses, particularly along the shelf break nearby Cape Katakolo. In the recent past (Holocene?) major submarine failures have already occurred in the area and have probably triggered significant local tsunamis.

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